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(54) DOPPLER RADAR SYSTEM

(71) We, MULLARD LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2. a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to Doppler radar systems of the character comprising, a transmitter for transmitting signal, a receiver for receiving a Doppler-shifted echo signal from a moving object, and a mixer stage for mixing the echo signal with a portion of the transmitted signal to provide a beat signal the frequency of which is indicative of the speed relative to the system of the moving object.

In a radar system of the above character, the presence of noise could affect the beat signal sufficiently to give rise to a false speed indication or indicate a moving target when non-existant. A possible way of reducing such an affect due to noise would be to provide a threshold level that noise was unlikely to exceed in normal operation of the system, and to arrange that the beat signal had to be above this threshold level before a speed indication could be derived from the beat signal. However, if noise increased to above the threshold level due, say, to partial component failure, then in this circumstance noise could still give rise to a false speed indication.

The present invention proposes a Doppler radar system including means which, in response to noise likely to give rise to a false speed indication, inhibits the production of any speed indication.

According to the present invention there is provided a Doppler radar system comprising a transmitter for transmitting a signal, a receiver for receiving a Doppler-shifted echo signal, a first mixer stage for mixing the echo signal with a portion of the transmitted signal to produce a first beat signal, phase delay means for producing said echo signal a second, phase-delayed, echo signal, a second mixer stage for mixing said second echo signal with a portion of the transmitted signal to produce a second beat signal which has the same frequency as the first but is phase-shifted with respect thereto, phase detector means responsive for each cycle of the two beat signals to produce a first output when their relative phasing is within specified limits, and a second output when their relative phasing has shifted outside these limits, indication means responsive to one of said two beat signals to provide a movement indication of an object or to provide in accordance with the frequency thereof an indication of the speed relative to the system of such object, and inhibiting means responsive to inhibit response of said indication means for a predetermined period when either one of said first and second outputs is produced and to maintain the inhibiting condition for a further such period if the other output is produced within said predetermined period.

Conveniently, the frequency measurement of one of the two beat signals, preferably the first beat signal, to provide the indication of the speed relative to the system of a moving object, can be made by determining the number of zero crossings of that beat signal in a given time. However, noise can alter the positions of the zero crossings of the beat signals, cause additional crossings, and also produce an output in the absence of the beat signals. If these effects of noise cause the output from said phase detector means to change within said predetermined period, the output transition, in either direction, is used to activate the inhibiting means to inhibit the counting of the zero crossings which, being partly or wholly due to noise, are partly or wholly uncorrelated in the respective signal channels for the two beat signals.

The invention is based on this premise that noise in respective signal channels for the two beat signals will be largely uncorrelated. In a preferred embodiment of the invention the two beat signals are nominally 90° phase spaced. One of the said two beat signals, preferably the first beat signal, is considered as a reference with the other beat signal being allowed, in effect, to wander in phase relative

to it, due to noise, by just less than $\pm 90°$ before the inhibiting means is activated. If, say, each zero crossing of said other beat signal does not shift by more than $\pm 90°$ from the nominal 90° phase spacing of the two beat signals and provided each crossing occurs, then the average frequency of the two beat signals must be correct provided that frequency measurement takes place long enough to cover noise-to-noise decorrelation time, that is, long enough to establish that a change in frequency is not only of a sufficiently short duration as to be likely to be due to noise. Thus, the phase detector means can be responsive to said other beat signal so that each time the beat signal used as the reference crosses zero in one preferred direction, the phase detector produces an output of the same polarity as said other beat signal and the output polarity is kept until the next zero crossing of the beat signal used as the reference occurs in the same direction. If the polarity of said other beat signal has not altered then the output polarity of the phase detector means remains unaltered. If, however, the two beat signals have phase-shifted relative to one another by more than 90° from their nominal 90° spacing, then the polarity of said other beat signal have changed so that the output polarity from the phase detector will be reversed.

The phase detector means is suitably a D-type flip-flop having a clock input to which a pulse is applied for each zero crossing in said one preferred direction of the beat signal used as the reference, this pulse being derived from this beat signal by a Scmitt trigger. A second Schmitt trigger is fed with said other beat signal and applies to a second (D) input of the D-type flip-flop a signal which is indicative of the polarity of said other beat signal. For each pulse at the clock input, the D-type flip-flop presents one or the other of two outputs having a polarity corresponding to the polarity of the signal supplied to its second input. Thus, the output polarity of the D-type flip-flop will change if the polarity of the signal applied to its second input changes between one clock pulse input and the next.

The outputs from the D-type flip-flop can be applied to a full-wave bridge circuit which feeds a CR time constant circuit with a signal in response to each transition of the output polarity from the D-type flip-flop. This CR time constant circuit determines said predetermined period in that for each polarity transition it inhibits a speed indication meter for said period. If a further output polarity transition occurs within said period then the inhibiting condition is maintained, otherwise the CR time constant circuit removes the inhibiting condition at the end of said period. The period may be, for example, one second. In practice, it may be undesirable to have the inhibiting condition imposed for an odd one or two phase jumps of greater than $\pm 90°$. If this is the case, a delay can be introduced before the CR time constant circuit becomes operative so that only a significant number of such phase jumps will bring about the inhibiting condition. This delay can be, for example, about 0.1 second.

In order that the invention may be more fully understood, reference will now be made, by way of example, to the accompanying drawings, of which:—

Figure 1 is a block diagram of a Doppler radar system embodying the invention;

Figure 2 shows diagrammatically one form of microwave circuit for the system of Figure 1;

Figure 3 illustrates the Doppler output from the microwave circuit;

Figure 4 is a simplified circuit diagram of a speed indicator circuit for the system of Figure 1; and

Figure 5 is a simplified circuit diagram of a speed meter inhibited circuit for the system of Figure 1.

Referring to Figure 1, the radar system there shown has an aerial 1 and a microwave circuit 2 which is of any suitable known form appropriate for producing two Doppler signals in phase quadrature. A microwave source of energy 3, which is suitably a Gunn oscillator, provides microwave power for the system. The two Dopper signals are amplified in separate channels A and B by respective amplifiers 4 and 5. The amplified Doppler signals are applied to respective Schmitt triggers 6 and 7 to "square" them. The resulting square-wave pulse in channel A are applied to a speed or movement indicator circuit 8 which is responsive to these pulses to drive a speed or movement meter 9. The system further comprises a phase detector 10 to respective inputs of which the square-wave pulses from the Schmitt triggers 6 and 7 are applied. The purpose of the phase detector 10 is to detect the relative phase of the square-wave pulses applied to its two inputs (thereby detecting the relative phase of the two Doppler signals in the channels A and B) and to produce a first output signal when the relative phasing of two such pulses is within a $\pm 90°$ range, and a second output signal when the relative phasing has shifted outside this range. Conveniently, the phase detector 10 is a D-type flip-flop having a clock input to which the square-wave pulses in one channel (e.g. channel A) are applied and a second input, the D input, to which the square-wave pulses in the other channel are applied. For each pulse at the clock input, the D-type flip-flop produces an output signal of polarity corresponding to the polarity of the pulse applied to its second input, the D-type flip-flop being triggered by the positive edge (or possibly the negative edge) of each pulse applied to its clock input. Thus, the

polarity of the output signal will change if the polarity of the pulse applied to its second input changes between one clock pulse input and the next. The two anti-phase output signals from the phase detector 10 are applied to a centre zero meter 11 which gives a left or a right deflection in dependence on the polarity of the output signal.

A Doppler radar system as so far described above can provide both direction sense and speed of a target, the direction sense being deduced by phase comparison of the two Doppler signals. The present invention is particularly suited for use in this type of Doppler radar system because most of the features required for carrying the invention into effect are already present in the system. Thus, for the sake of completeness and to facilitate a better understanding of the present invention, the derivation of and significance of the phase relationship between the two Doppler signals will now be considered.

The microwave circuit 2 in the system of Figure 2 can be of the form shown in Figure 2, this microwave circuit including a circulator 12 which enables the use of a single aerial (1—Fig. 1) for both transmission and reception. Microwave power from the Gunn oscillator 3 is applied to port 13 (Fig. 1) and flows to the aerial via port 14. Power applied to port 14 from the aerial (i.e. a Doppler-shifted echo signal from a target) is routed via port 15 to two hybrid rings 16 and 17 via respective paths 18 and 19 which are of different lengths such that the echo signal at hybrid ring 17 is delayed by 90° with respect to the echo signal at hybrid ring 16. The microwave circuit also includes a coupler 20 which applies a portion of the microwave power at port 13 to the two hybrid rings 16 and 17. In each of the two hybrid rings 16 and 17 the instantaneous amplitudes of the two signals applied thereto are added together to produce a sum signal and respective mixer diodes 21 and 22 detect the sum signal and produce a direct output voltage which varies in amplitude in accordance with the variation in phase relationship between the two signals. This variation in phase relationship is due to target movement (either approaching or receding) in that if a target is approaching the system there will be an apparent increase in the frequency of the echo signal relative to the transmitted signal, whereas if a target is receding from the system there will be an apparent disease in the frequency of the echo signal relative to the transmitted signal. A Doppler or beat signal which has a frequency that is indicative of the speed of such movement and an amplitude indicative of movement alone is obtained by means of a capacitor 23 or 24 from the amplitude variation of the direct output voltage at the mixer diodes.

Thus, the microwave circuit produces two identical Doppler signals which are nominally 90° phase spaced. Either one of these two Doppler signals, in this instance the signal applied to channel A in the system of Figure 1, can be utilised for speed indication purposes. Also, the two Doppler signals, taken in conjunction, are utilised as follows to determine direction of movement (either receding or approaching) of a target with respect to the system. When a target is approaching the system and reaches a position for which the amplitudes of the two signals supplied to the hybrid ring 16 sum to a maximum, the maximum of the sum of the amplitudes of the two signals applied to the hybrid ring 17 is about to occur a little later in time when the path length for the Doppler-shifted echo signal has shortened by another quarter wavelength. In other words, the amplitude modulation of the sum signal from hybrid ring 17 lags that from hybrid ring 16 by a quarter wavelength (90°), where the wavelength is being measured at microwave frequency, but the Doppler signals are normally being produced at audio frequency. Conversely, it will be apparent that when a target is receding from the system, the amplitude modulation of the sum signal from hybrid ring 17 leads that from hybrid ring 16 by a quarter wavelength. These phase relationships of the two Doppler signals are shown in Figure 3 in which wave A represents the Doppler signal in channel A, wave B*a* represents the Doppler signal in channel B for an approaching target, and wave B*r* represents the Doppler signal in channel B for a receding target.

From the waveforms in Figure 3, it can be seen that when wave A is crossing zero, in say the positive-going direction, the sign of the wave B (i.e. B*a* or B*r*) indicates the direction of target movement. Furthermore, since the zero crossing of wave B is nominally situated in the middle of wave A (i.e. where wave A has a maximum amplitude), maximum relative phase displacement of the waves A and B due to circuit inaccuracies is possible before any logic that determines the direction sense from these waves can give a wrong answer. As already described, in the system of Figure 1, the relative phasing of the waves in channels A and B is determined by the phase detector 10 from square-wave pulses devised by the Schmitt triggers 6 and 7 from these waves, the wave in channel A being used as a reference, with the wave in channel B being allowed, in effect, to wander in phase relative to it by ±90° before the polarity of the output signal from the phase detector 10 changes. Thus, the left and right deflections of the meter 11 in response to the phase detector output signals indicate direction sense (i.e. approaching or receding) of a target.

The waves (Doppler signals) in channels A and B are also utilised in accordance with the

invention to inhibit the speed meter 9 in the event that a false speed indication is likely due to noise. The presence of noise in the channel, in this instance channel A, for the Doppler signal used for speed indication, can give rise to additional zero crossings of this Doppler signal. In such an event, the frequency of the pulse output from the Schmitt trigger concerned becomes higher than the true frequency of the Doppler signal with the result that a false speed indication is given. Also, it is possible that the speed meter 9 will give a reading on a noise signal alone in the absence of a Doppler signal. However, there will also be noise in the channel (B) for the other Doppler signal which will be largely uncorrelated with the noise in channel A, because it has been found that the noise in each channel is due predominately to the system components, in particular, to the input stages of amplifiers 4 and 5 and the mixer diodes 21 and 22. Therefore, any change in the phase difference of the two Doppler signals by more than 90° which takes place within a suitable measuring time can be said to be due to noise, because these two Doppler signals are of the same frequency, (where frequency is defined as the number of zero crossings per unit time) so that their phase difference should not differ by more than 90°, except for any single phase change due to the change in direction sense of a target. For a system in which the frequency of the Doppler signal(s) can be as low as 1Hz, the period of the measuring time may be 1 second.

Thus, in accordance with the invention the system of Figure 1 includes a speed meter or presence inhibit circuit 25 to which the output signals from the phase detector 10 are also applied. As will be described with reference to Figure 5, this inhibit circuit 25 is responsive to the phase detector output signals to inhibit the speed meter 9 for said period, so that it gives no speed reading, each time there is a change in the output signal polarity. The result of this is that the inhibiting condition is maintained for a further such period if the output signal polarity changes within a period that the speed meter 9 is being inhibited. However, as will also be described with reference to Figure 5, the inhibited circuit is preferably so arranged that it only imposes the inhibiting condition for a significant number of polarity changes of the phase detector output signal, as would occur with persistent noise.

In the system of Figure 1, the elements 2, 3, 4, 5, 6 and 7 can all be of known form, so that further description of these elements is though to be unnecessary for an understanding of the invention. Only the speed indicator circuit 8 and the speed meter inhibit circuit 25 are thought to require further description, and these two circuits will now be considered with reference to Figures 4 and 5. The use of a D-type flip-flop as the phase-detector 10 forms the subject of our co-pending U.K. patent application No. 13241/73 (Serial No. 1357457) which is divided from the present application.

The speed indicator circuit of Figure 4 drives the speed meter 9, which is a moving coil meter, with a direct current proportional to target speed. To achieve this, this circuit generates a fixed length pulse for each half cycle of the Doppler signal in channel A by means of a monostable element comprised by transistors 26 and 27, these pulses being integrated by a capacitor 28, which is connected across the meter 9, to produce the direct current. The capacitor voltage is small and so there is negligible integration error. The monostable element is fed with pulses from two transistors 29 and 30. The transistor 29 is actually a part of the Schmitt trigger 7, and the transistor 30 produces an anti-phase wave form. Thus, triggering of the monostable element occurs for each half cycle of Schmitt trigger output via two triggering diodes 31 and 32 and capacitors 33 and 34. Of course, it would be possible to dispense with the transistor 30, capacitor 34 and diode 32, so that triggering of the monostable element occurs only for each complete cycle of the Schmitt trigger output.

The speed meter inhibit circuit of Figure 5 comprises a diode bridge 35 which is fed via respective capacitors 36 and 37 with both outputs from the phase detector (10). Thus, a single change in polarity of the phase detector output signal will turn on a transistor 38 for a short period. During this period, assume that a capacitor 39 discharges sufficiently through transistor 38 to cause a further transistor 40 to turn off. When transistor 40 turns off, two other transistors 41 and 42 are turned on and the collector of transistor 42 clamps the speed meter 9 (Figure 4) to zero. Provided there is no further change in the polarity of the phase detector output signal for the next second (i.e. the suggested period of the measuring time referred to previously), the capacitor 39 will charge up sufficiently via a resistor 43 to turn on transistor 40 again, so that transistors 41 and 42 will turn off and the speed meter 9 will be unclamped. If there is a further change in the polarity of the phase detector output signal within the next second, transistor 38 will turn on again for a short period so that charge on capacitor 39 will be removed, when the inhibiting condition will be maintained for a further second. However, in order that the inhibiting condition should not be imposed for only an odd infrequent change in the polarity of the phase detector output signal, as might be produced by a short noise "spike", a resistor 44 is provided in the discharge path of the capacitor 39. This resistor 44 increases the time to, say 0.1 second, for capacitor 39 to discharge suffi-

ciently to cause transistor 40 to turn off. The delay chosen is sufficient to keep transistor 40 turned on during a single turn on period of transistor 38, so that only a significant number of turn on periods of transistor 38 in quick succession will allow capacitor 39 to discharge sufficiently to turn off transistor 40.

A radar system as described herein can be designed for use as an intruder alarm. Thus, using the allocated intruder alarm frequency of 10.687 GHz, a target speed of 1 m.p.h. would give a Doppler signal frequency of 31.8Hz. Lower target speed would give correspondingly lower Doppler signal frequencies which, as aforesaid, could be as low as 1Hz. In this use as an intruder alarm the invention, although primarily concerned with imposing a movement inhibiting condition in the presence of noise, offers the advantage that, by selection of a suitable timing period for determining whether or not the inhibiting condition should be applied, it can be arranged not to produce a false intruder alarm condition in response to, say, a fluttering curtain by reason that the latter would cause phase detector output polarity changes within the timing period.

WHAT WE CLAIM IS:—

1 A Doppler radar system comprising a transmitter for transmitting a signal, a receiver for receiving a Doppler-shifted echo signal, a first mixer stage for mixing the echo signal with a portion of the transmitted signal to produce a first beat signal, phase delay means for producing from said echo signal a second, phase-delayed, echo signal, a second mixer stage for mixing said second echo signal with a portion of the transmitted signal to produce a second beat signal which has the same frequency as the first but is phase-shifted with respect thereto, phase detector means responsive for each cycle of the two beat signals to produce a first output when their relative phasing is within specified limits and a second output when their relative phasing has shifted outside these limits, indication means responsive to one of said two beat signals to provide a movement indication of an object or to provide in accordance with the frequency thereof an indication of the speed relative to the system of such object, and inhibiting means responsive to inhibit response of said indication means for a predetermined period when either one of said first and second outputs is produced and to maintain the inhibiting condition for a further such period if the other output is produced within said predetermined period.

2. A Doppler radar system as claimed in Claim 1, wherein said two beat signals are nominally 90° phase spaced, and wherein one of said two beat signals is considered as a reference with the other beat signal being allowed, in effect, to wander in phase relative to it by just less than ±90° before the inhibiting means is activated.

3. A Doppler radar system as claimed in Claim 2, wherein the first beat signal is used as the reference.

4. A Doppler radar system as claimed in Claim 2 or Claim 3 wherein the phase detector means is responsive to said other beat signal, each time the beat signal used as the reference crosses zero in one preferred direction, to produce an output of the same polarity as said other beat signal and to keep that output until the next zero crossing of the beat signal used as the reference occurs in the same direction, the output polarity of the phase detector means remaining unaltered if the polarity of said other beat signal has not altered, and the output polarity of the phase detector means being reversed if the polarity of said other beat signal has changed due to the two beat signals having phase-shifted relative to one another by more than 90° from their nominal 90° spacing.

5. A Doppler radar system as claimed in Claim 4, wherein said phase detector means is a D-type flip-flop having a clock input to which a pulse is applied for each zero crossing in said one preferred direction of the beat signal used as the reference, this pulse being derived from this beat signal by a Schmitt trigger, and wherein a second Schmitt trigger is fed with said other beat signal and applies to a second (D) input of the D-type flip-flop a signal which is indicative of the polarity of said other beat signal, the D-type flip-flop presenting for each pulse at the clock input one or the other of two outputs having a polarity corresponding to the polarity of the signal supplied to its second input.

6. A Doppler radar system as claimed in Claim 5, wherein the outputs from the D-type flip-flop are applied to a full-wave bridge circuit which feeds a CR time constant circuit with a signal in response to each transition of the output polarity from the D-type flip-flop, this CR time constant circuit determining said predetermined period in that for each output polarity transition it inhibits a speed indication meter for said period.

7. A Doppler radar system as claimed in any preceding claim, wherein said predetermined period is one second.

8. A Doppler radar system as claimed in Claim 6, or Claim 7 as appended to Claim 6, including means for introducing a delay before the CR time constant circuit becomes

operative to inhibit the speed indication meter.

9. A Doppler radar system as claimed in Claim 8, wherein said delay is 0.1 second.

10. A Doppler radar system substantially as hereinbefore described with reference to the accompanying drawings.

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1357456 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

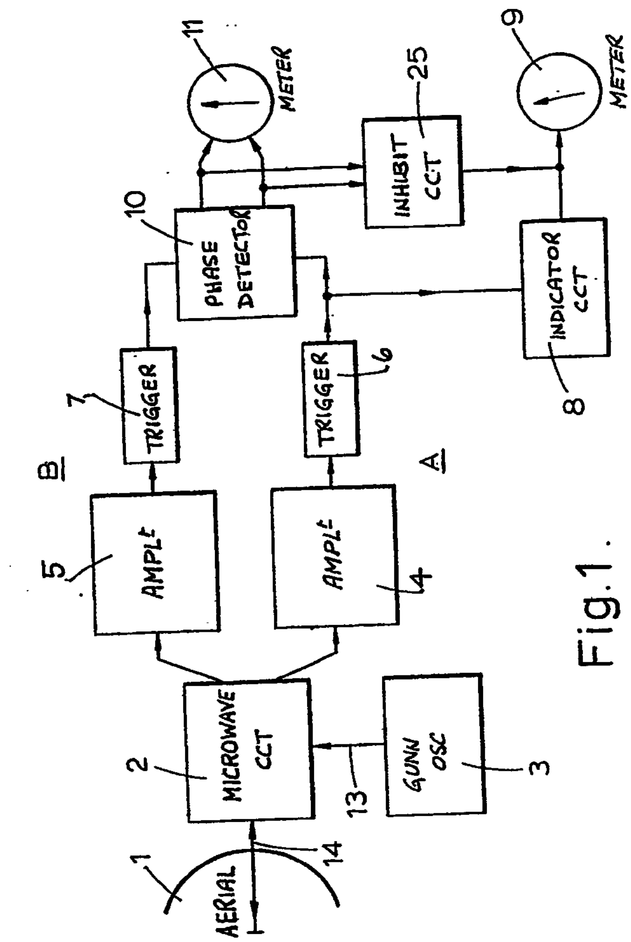

Fig.1.

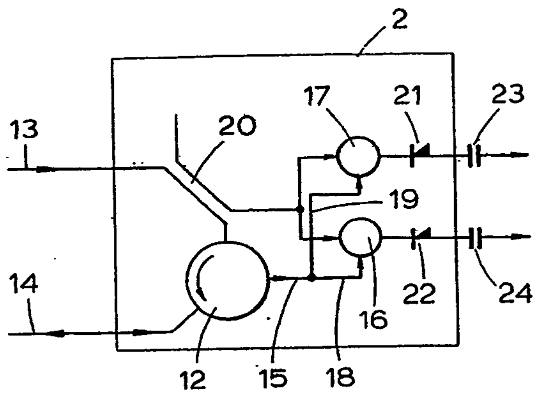

Fig. 2.

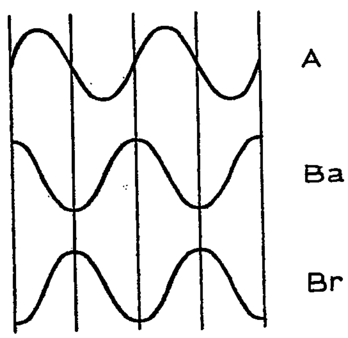

Fig. 3.

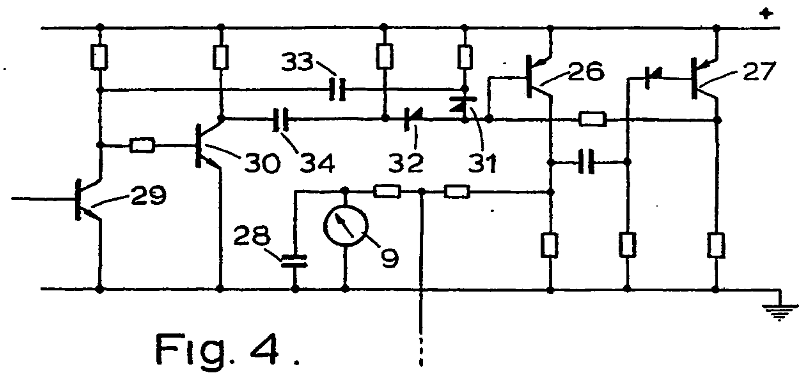

Fig. 4.

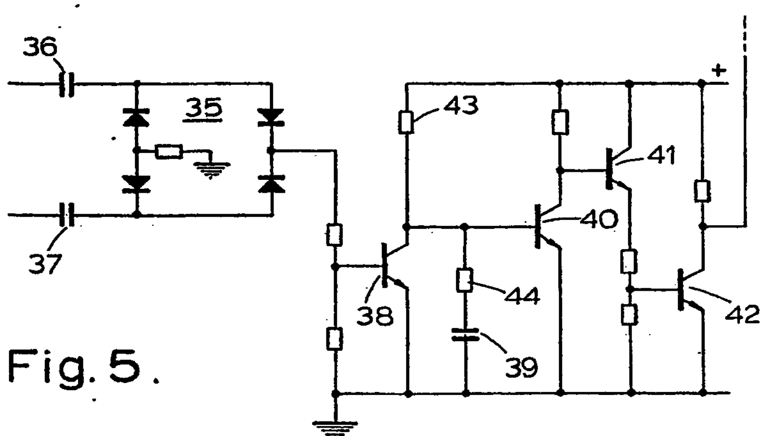

Fig. 5.